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MOFFAT TUNNEL

By J. M. WEED, *Department Civil Engineering*

Cuts by courtesy Denver Municipal Facts and Mr. C. A. Betts, Office Engineer.



IX and eleven-hundredths miles long. The longest railroad tunnel in America, fifth longest railroad tunnel in the world. That's the Moffat Tunnel.

Going west from Denver, the transcontinental traveler has had to veer widely from his course, either north to the U. P. trail through Wyoming or south past Pike's Peak and through the Royal Gorge. The high and rocky mountains to the west have proved a wall effectual for blocking transportation and economic development. Over the mountains are water, timber, coal, rich agricultural land, undeveloped and inaccessible. D. H. Moffat saw the need, labored for a low-grade railroad, was able to build the line after compromising on a location over Corona Pass, 11,660 feet above sea level.

But in this location the railroad has been unable, literally, to "make the grade." There are four per cent grades so that four big engines are required for twenty-car trains. There are snows which block traffic sometimes for days at a time.

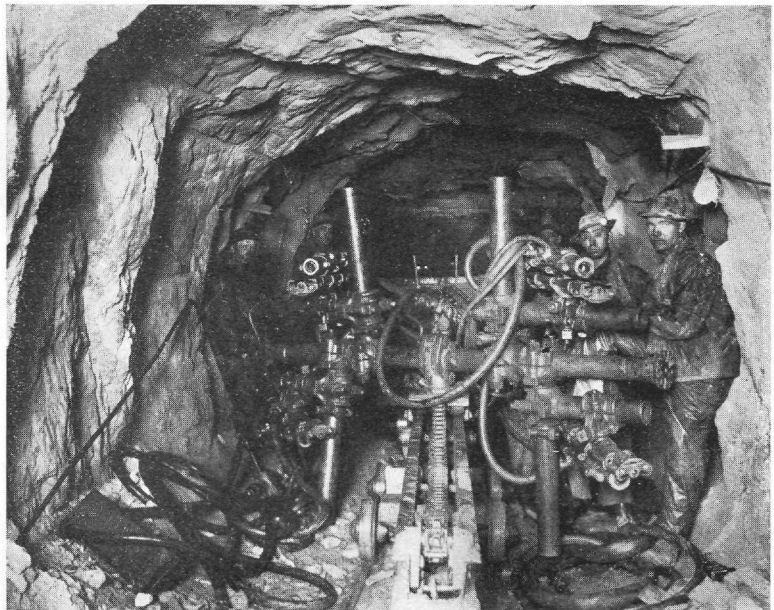
Now a tunnel is being built which will do away with these difficulties. Twenty-three miles of track will be cut out. The four per cent grades will be eliminated. The journey west—as soon as proper connections are made—will be shortened by 173 miles, or one-quarter of a day. This tunnel has, very appropriately, been named for the man who first had the vision of it.

The Moffat Tunnel proper is a railroad tunnel, sixteen feet wide and twenty-four feet high, through the Continental Divide in Colorado, about fifty miles west of Denver. For supply, ventilation, and haulage purposes during construction, and as a conduit for water later on from the Pacific slope to the City of Denver, a tunnel eight by nine feet in size and seventy-five feet south of the center of the railroad tunnel is being built at the same time; this construction or service tunnel is usually referred to as the water tunnel. About every 1,500 feet a cross-cut connects the two tunnels. From these cross-cuts excavations or "headings" may be made in the railroad tunnel in both directions. Thus the water tunnel makes possible construction in several more places than the two ends of the main tunnel.

The west end of the tunnel was the one I first became acquainted with. Phil Parker, a young Nebraska engineer, asked me to help him do a little lining up. The "dry house" at the entrance to the water tunnel was noisy with the rumble of fans, smelly with the odor of perspiration from the clothes of the "muckers" who did their changing there. No train was going in then so we had to walk "into the bowels of the earth," as the feature writers always put it. It was rough going over the ties of the little railroad track, two-foot



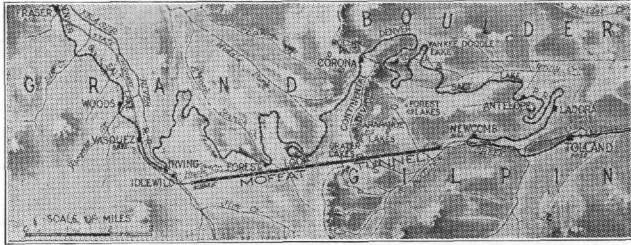
The widening of the top heading requires careful packing between the segmental timbers to keep the roof arch stable.



Drill carriage mounting four drills which permits setting up in fifteen minutes and is adapted to the twin handling system of drilling.



Draft doors in crosscut to direct the air waves.



A Straight Line

gauge, looking for all the world like the line in an Ohio coal mine. The tunnel looked like a mine, too, with roof and posts, for the stone was too soft to stand alone. When we passed beyond the reach of the sun—and the train-butchers say a Colorado sun is 70% brighter than those back East—the going was even rougher, for though there were many electric lamps they glowed rather feebly through the smoke. The lamps do better now, for the smoke is blown out through the railroad tunnel, but when I made this first trip the air in the water tunnel was sometimes pretty heavy with it. Skidding down between the ties was not so pleasant, for my boots leaked. The Moffat is not a wet tunnel, but often there were trickles from the roof and a fair sized little brook ran along the track.

Overhead were electric wires, one pair of them 2,300 volts. On the tunnel wall were a large pipe for ventilation air, a smaller one for compressed air, still a smaller one for water. The compressed air pipe was troublesome; it seemed alive with a clattering which filled the whole passageway.

"Just the vibration from the compressed air drills," said Phil. "You'll soon get used to it."

But it has its drawbacks—drowns out the rumble of trains. A light approached, dim and yellow through the smoke, and Phil pulled me off to one side and flattened me against the dripping wall. A locomotive and train of loaded cars galloped by.

The method de luxe for exploring the tunnel is to go in perched atop of one of the locomotives. One climbs aboard the locomotive, is cautioned to keep head down out of the way of the wires and arms and legs from sticking out beyond the allowable limit. The workmen climb in the cars—car loads of 'em. And doubtless, after a hard day at mucking, the clattery ride to daylight—or it may be midnight darkness, for they work the clock around, three shifts to the 24 hours—the clattery ride out is as springy and pleasant, doubtless, as the jaunt home in the ricketiest Ford after a day at driving stakes on the road.

In the open space at one of the cross-cuts we found a little gang of muckers waiting, enjoying a little rest from work.

"Fire in the railroad tunnel," said Phil. I wondered how the blast would sound so far underground, wondered if I should hold my fingers to my ears, tried to

look nonchalant, for I was ashamed to appear green. When the blast came I felt rather than heard it. The air seemed to push against us. It blew out the acetylene torch I was carrying. The workmen counted. All the charges had exploded. When the smoke had cleared away they went back to work.

Stumbling along we reached the last cross-cut, crossed over into the headings of the main tunnel. Progress seemed to be good in one end; the stone was, for a brief interval, hard enough so timbering was not necessary. In the other heading conditions were not so pleasant; water was pouring from the roof with all the persistence of a November rainstorm. But men were at work there, sweating, swearing, drilling holes in the rock face and getting ready for the next shot.

The rock which would stand without support was just a little pocket. In the very end of the water tunnel the men were loading into a car the softest kind of soap-stone.

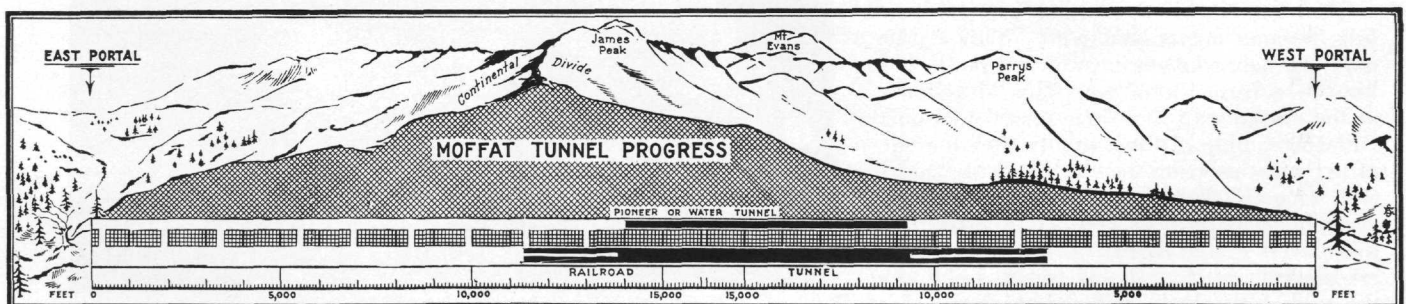
"That's a mucking machine," shouted my guide, above the rattle of the machinery. It was an interesting creature. Its snout, with loose hanging jaw, much like the bucket of a steam shovel, was rooting eagerly in the pile of broken stone at the end of the opening. With a grinding groan the mouth was raised and the stone swallowed, dumped on a belt which carried it up an incline and dropped it into the work car just behind. Occasionally there was some straining to lift an extra heavy piece, but the monster managed to eat all that was set before it. Then it had to retire until some more track was laid, some more holes drilled, enough stone blown down for another meal.

"Muck" probably sounds like the kind of mud found in the bottom of a bog. And that term is not inappropriate for some of the low, degenerate stone from the west side, soft mica schists and talcs hardly worthy to compose the backbone of America. One has to get used to "muck" for even the hard granite of the eastern portal.

Phil and I had come in to do some work. He set up his transit *under* the plumb bob, which dangled from a hook in the roof of the tunnel. I went back quite a distance to give him a backsight, the string of a plumb bob suspended from another hook. Just behind the string I held the acetylene torch and a piece of scratched (it would be more elegant but less truthful to say "ground") glass; the diffused light made the string visible through the telescope. To fasten the plumb bob to the hook I had to stand on a box and support myself by grasping the 2,300 volt wire. That was the worst thing about it.

That was back in 1924. A tour of the tunnel is a bigger job now; in fact it would be economy to wait for a train rather than walk in to work. It's over two miles to the extreme end of the tunnel from the west end; nearly three miles from the east end. Even so, it's a mile and a half, a pretty thick stone wall, which separates the ends of the tunnel from each other.

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MOFFAT TUNNEL

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Here are the latest figures on the progress of the work:
Progress to December 15, 1925

	East (feet)	West (feet)	Total (feet)	Finished (per ct.)
Water tunnel	14,028	10,741	24,769	76.6
Main headings	14,037	10,683	24,720	76.5
Cross cuts	567	441	1,008	77.0
Full size railroad.....	11,343	4,463	15,806	49.0

The high point in the tunnel is reached by a .3% grade from the east end, and .9% from the west end. Now the east side men are past the apex and working down the slope toward West Portal.

The system developed in driving the water tunnel and headings has enabled the builders of the Moffat Tunnel to beat the world's records. While the drillers are getting ready for the shots in the water tunnel, the men are cleaning up the muck in the extreme end of the railroad tunnel heading. After the drilling and shooting have been done in the water tunnel, the operations are reversed; the drillers go to the railroad heading and the muckers to the water tunnels. When the rocks are breaking right this alternate division of the work makes possible about 24 feet of advance every day, so the two ends are approaching each other at the rate of nearly 50 feet a day.

Getting the water tunnel and headings of the main bore—the first holes—through the mountain is a big job, but making the railroad tunnel large enough to run trains through is a bigger one. In the east end where the stone is hard, timbering practically unnecessary, and going fairly easy, the heading is made near the middle of the railroad tunnel and then enlarged all 'round. In the west end everything has to be braced to keep from caving, headings and all. Here the headings are made near the top. Then the top is made full width and the timber arch put in. But it is still about sixteen feet to the bottom of the tunnel, and while this part is being excavated the arch must be supported. George Lewis, the chief engineer, solved that problem. He invented the Lewis cantilever needle beam which rests on the "bench" (the rock just below the heading) and supports about fifteen feet of arch while the bench is being dug out beneath it and the posts are being put in. When all is secure the needle beam is pulled along by an electric hoist and another fifteen-foot bite taken.

Timbering is a big item. The lumber estimate now is for six million feet of Oregon fir and three million feet of Colorado pine. The pressure on the bracing is tremendous. Some of the first posts put in were completely shattered. Now the sticks used seem to be large enough, the huge twelve by eighteens. Pretty hefty pieces of timber; a foot by a foot-and-a-half and sixteen feet long would be 24 cubic feet, which would mean a weight for each post of about 1,200 pounds. The posts are pretty close together, too; in places the spacing is a foot or two; sometimes they are side by side.

The east end of the tunnel has been well behaved, solid, requiring scarcely any timbering. True there are a few soft places; one is where Crater Lake leaked through and threatened to drown out operations with a flood of 1,800 gallons a minute. But most of the way the rock stands alone.

The Moffat is not a wet tunnel—comparatively speaking. But just recently the east side headings ran into about 500 gallons a minute. That's a good-sized stream and rather hard to handle, particularly since it's "over the hill" and has to be pumped out.

The headings are enlarged by "ring shooting." Holes are drilled, raidating in starfish fashion from the center

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MOFFAT TUNNEL

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of the heading, to the neat line of the finished tunnel. This work must be done with great care to get the angles and lengths of the holes just right. The drills are guided and supported on a drill carriage which runs on the tracks.

Where the headings are being enlarged to full size the service tracks are double, three-foot gauge; trolley locomotives and larger cars are used; the loading is done by air shovels. There are even air hoists to lift the empty cars from one track to another and help keep the loaded cars moving out in a steady stream.

They have taken out a lot of muck, too. When such a major operation as the Moffat Tunnel is performed, the amount of material removed is surprising. The dumps are pretty prominent in the valleys at both ends. There is plenty for the railroad approach fill, of course, with enough left over to change the scenery materially.

Speaking of scenery, this job affords it in variety. The East Portal is an unattractive region, bare, rocky, burned over. But the West Portal is an earnest of the richness of the region which the Tunnel is designed to develop. It is in a country of clear cold streams—yes, there are trout there—and tall, graceful, plumelike pines.

Rivalry between the two camps is intense. At both Portals are huge progress meters, and every day when the records at both ends are posted an eager crowd turns out to get the returns. There are bonuses, too, for advance beyond certain limits, so the men do not, certainly, lack incentives for rapid work.

The human factor is not at all neglected. Never before in the history of tunnel building were men so well taken care of. At each end of the tunnel is a city, East Portal, West Portal. There is a railroad station, postoffice, store, recreation room and theatre (Hoot Gibson and other Westerners are very popular). The men with families rent cottages, the others live in bunk houses. The big mess hall is perhaps the cynosure of each camp. For the huskies who are digging the Moffat Tunnel can certainly eat, some of 'em five times a day. When dinner is announced by the raucous squawk of an automobile siren there's a stampede for the mess hall. The food deserves such popularity, for it is splendid in variety and well cooked and served.

The official buildings come next in importance, probably, to the mess hall. The headquarters of the Tunnel Commission and the contractors are comfortable; the offices are roomy and the living quarters cozy, even to shower baths. In the power plants large quantities of Colorado mountain air are concentrated and made really useful in driving the drills and shovels. All the power comes in a 44,000 volt transmission line from the Boulder Canyon hydro-electric plant of the Public Service Company. In the blacksmith shops the drills are sharpened, a tremendous job, for sometimes at the East Portal 2,000 of them have been dulled in one day. The car shops for repairs to the larger machinery, the warehouses, the water supply plants—all are important and well organized.

A great work is being done at the Moffat Tunnel. All branches of engineering are represented, are interested. The City of Denver, the State of Colorado, the whole United States, will profit by the development of this rich region whose resources are scarcely tapped, a region containing, according to some geologists—to mention just one product—enough coal, and that of good quality, to supply the Nation for 1,500 years.

The dream of Mr. Moffat was the tunnel. Now his dream is coming true in the building of a monument which will keep his name immortal.